CONFIDENTIAL

30 JUL 1958
7220 - 7793 Copy 406
RM H58D21

NACA RM H58D21

7062

TECH LIBRARY KAFB, NM
0143735

NACA

RESEARCH MEMORANDUM

OPERATIONAL PROBLEMS OF MANNED ORBITAL VEHICLES

By Hubert M. Drake, Donald R. Bellman,
and Joseph A. Walker

High-Speed Flight Station
Edwards, Calif.

Classification cancelled (or changed to Unclassified)

By Authority of NASA Tech Pub Announcement #14
(OFFICER AUTHORIZED TO CHANGE)

By .... B. Marko
NAME AND

.... NK ....
GRADE OF OFFICER MAKING CHANGE)

17 Feb. 61 ....
DATE

CLASSIFIED DOCUMENT

This material contains information affecting the National Defense of the United States within the meaning of the espionage laws, Title 18, U.S.C., Secs. 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

July 21, 1958

CONFIDENTIAL

[redacted]

TECH LIBRARY KAFB, NM
0143735

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

OPERATIONAL PROBLEMS OF MANNED ORBITAL VEHICLES*

By Hubert M. Drake, Donald R. Bellman,
and Joseph A. Walker

SUMMARY

Manned orbital vehicles, because of their extreme performance and relative inflexibility of operation, introduce many problems in the fields of escape, piloting, orbit selection, flight termination, and range requirements. The effects of some of these problems, including some effects of configuration, are discussed.

No insurmountable operational problems were found regardless of configuration, but it is indicated that the problems of the various vehicle types materially affect operations and must be considered early in design. Safety and survival requirements may force appreciable deviation from optimum procedures. The presence of the pilot may simplify design and increase reliability. The type of vehicle has a considerable effect on range requirements, the more simple vehicles generally requiring increased range and recovery complexity.

INTRODUCTION

Manned vehicles of orbital performance potential introduce many operational problems as a result of their extreme performance and the relative inflexibility of their operations. The present paper discusses a few of the major problems and indicates their possible effects on flight research operations.

The vehicles being considered for possible use as manned satellites fall into the three general categories shown in figure 1. Briefly, the first vehicle is the ballistic-type, characterized by the use of drag alone for entry deceleration and heat-load reduction. The second category, the semiballistic vehicle, employs lift to reduce the peak decelerations and to provide some degree of aerodynamic flight-path control. The final category consists of what might be termed winged vehicles; that is, vehicles capable of aerodynamically efficient flight. It should be noted that this category may also be considered of the semiballistic

*Title, Unclassified.

[redacted]

[redacted]

type because lift-drag ratios as low as zero can be obtained by operating at high angles of attack. In general, only the ballistic and winged types are discussed in detail, inasmuch as the capabilities of the semiballistic-type fall between these extremes.

Although both vertical rocket-boost take-off and air-launch might be considered for orbital flight, the major operational problems for the two types of launch differ only during the initial phases. Since the vertical take-off presents the more stringent problems, it is the type considered herein. The general problem areas of escape, piloting, orbit selection, entry and flight termination, range requirements, and flight test program are discussed briefly.

SYMBOLS

H	altitude, miles
L/D	lift-drag ratio
q	dynamic pressure, lb/sq ft
V	velocity, ft/sec
V_v	vertical velocity, ft/sec
V_{orb}	orbital velocity, ft/sec
Y	lateral distance, miles
γ	flight-path angle, deg

DISCUSSION

Escape and Survival

The presence of the human in the orbital vehicle requires that malfunctions be either nondestructive, or such that an escape system can provide survival. The provision of a means of escape from all reasonable emergency conditions requires an escape system with all the characteristics of the final vehicle. It therefore appears that the final stage should be designed to serve as the major element of the escape system. A primary goal should be the design of the final stage and the tailoring of the entire flight operation to provide the greatest possible survival potential for this stage. In addition, a positive means of pilot separation from the final stage survival vehicle, such as a high-performance ejection seat, is required to permit the pilot to use his personal parachute for low-speed survival.

The presence of propellants, the take-off operation, stage separation and ignition, and high dynamic pressure combine to make the launch operation the most critical escape region (fig. 2). Significant survival regions are indicated generally by the lettered areas on the launch trajectory of figure 2 and are further described in table I. The boundaries of these various escape areas vary, of course, with the configuration and its design characteristics. In some designs or operations a given region might not exist, being absorbed by an adjacent one. An example of this is the case of air launching, where region A is in general absorbed by region B. In the present discussion only two of the indicated regions, A and C, are discussed in any detail.

Escape at lift-off, region A, is difficult in that the use of the ejection seat would require its reorientation, and the normal final stage power plant, in general, possesses insufficient acceleration to permit satisfactorily rapid separation from a malfunctioning first stage. A possible escape technique consists of providing high-thrust, jettisonable, solid rocket units attached to the final stage survival vehicle. Rockets sufficient to remove this vehicle from the launching pad to an altitude of 1,000 feet and a speed of 300 knots within 3 to 4 seconds would probably be adequate for escape from all take-off accidents not involving an actual detonation. This end condition permits airplane final stages to be airborne and, should this stage have an engine, allows sufficient time for an attempted engine start. Should the engine fail to start, a gliding landing can be made if possible, or the ejection seat may be used. Ballistic or semiballistic vehicles can make a normal parachute landing. These auxiliary rockets and any necessary stabilizing surfaces should be retained to the altitude at which a normal separation and recovery can be made. During an investigation of an example of such a system, it was found that carrying the system to an altitude of about 20,000 feet reduced the first stage burnout velocity by only about 50 feet per second. It might be mentioned that, although the ejection seat is listed only for region A, it is assumed to be available in all cases for use at low speed as needed.

Another critical area for escape and survival is that indicated as region C in figure 2 and table I where a malfunction may subject the final stage to conditions which it, or its passenger, cannot survive. The criticality and extent of this region are greatly influenced by such design and operational factors as the type of vehicle, use of final stage power, launch trajectory, lift-drag ratio, structural design, and lift or drag loading. With the ballistic vehicle in this region there is a danger that the man will be subjected to excessive decelerations in

AF[redacted]

case of booster malfunction as shown in figure 3. In this figure the solid line indicates the decelerations encountered in the event of a malfunction during the normal gravity-turn launch of a ballistic vehicle. The decelerations in this case reach values of about 22g at a launch malfunction velocity near 15,000 feet per second. Substantially higher values are possible for other ballistic configurations. It might be well to note that the final satellite vehicle would also have a peak deceleration near 22g at malfunction speeds near 2,000 feet per second if it were separated from the boosters at this point. This results from the high dynamic pressure at this point. The lower decelerations shown for these low speeds result from retaining with the vehicle the final boost stage, unfired, to increase its sectional density during the coast to high altitude following malfunction. Separation of the final vehicle at the peak of the coasting period will then result in decelerations near 2g.

Possible means of reducing the decelerations resulting from malfunctions at the higher speeds during launch of course include the use of lift (as with the semiballistic vehicle), provision of thrust to reduce flight-path angle, and variable drag geometry. Another possibility is the use of a launching trajectory which has been modified in such a manner that the vehicle will, in case of booster failure, always enter the atmosphere at a sufficiently flat angle to keep the decelerations to a tolerable level. A first approximation to such a trajectory has been calculated for the example ballistic vehicle and the resulting decelerations are shown as the line labeled "safety" trajectory (fig. 3). In this case the peak decelerations have been reduced one-half, with a peak value of about 11g.

Figure 4 shows that this "safety" trajectory is considerably flatter than the optimum gravity-turn launching path, thus subjecting the boosters to higher aerodynamic and control loads and to increased heating. These factors may result in a further performance penalty above that incurred by the use of the nonoptimum trajectory. This performance penalty must be judged against the costs of other means of insuring survival in this region. It might be noted that figure 4 does not show the entire launch operation for the "safety" trajectory. The conditions at the burnout point shown yield an elliptical orbit having an apogee at 150 miles, and an additional (small) speed increment must be applied at this point to obtain the desired circular orbit.

A similar condition exists for the winged vehicle in region C (table I). In this case there is a possibility, following booster failure, that the vehicle will be forced to perform a skipping entry under conditions that will expose it to excessive heating. A similar trajectory modification can be made to avoid this region. Here, again, possible use of final-stage thrust can greatly alleviate the problem. The investigation of "safety" trajectories has been a neglected field of research which must be explored for manned satellite operations.

It is difficult to envision a reason for evacuating the vehicle in orbit, region D; however, a malfunction in orbit may make the entry operation hazardous. Examples of such malfunctions are the failure or explosion of auxiliary power units and their fuel tanks, and the failure of stabilization systems. Adequate reliability, isolation, and duplication of such critical systems are the best safety and survival provisions. The prevention of such accidents should be a primary design goal. In some designs if adequate reliability cannot be attained it may even be necessary to incorporate a special simple escape capsule of the drag-entry type for orbital or entry escape.

It might be well to emphasize a point that has been implied throughout the foregoing; that is, that the final stage should be designed with the most reliable power plant and auxiliary power system possible. The final stage power plant can, by reliable stop and restart capabilities, greatly alleviate many otherwise dangerous emergencies.

Piloting

Although complete automatic stabilization and control of the manned satellite throughout its flight is feasible, it would be desirable to take advantage of the abilities of the pilot to simplify the system and thus increase the reliability and safety of the operation. An exploratory analog simulator investigation has been made to determine the accuracy with which a pilot could fly a three-stage vehicle to a desired orbit at an altitude of 100 miles. The guidance used consisted of a presentation of error between programmed and actual pitch angle, and indications of altitude, rate of climb, velocity, and angle of attack. Figure 5 shows some of the results of this investigation. The left side of the figure indicates the accuracy in angle and velocity required to maintain the orbit perigee above 75 miles and indicates the manner in which an error in angle can be compensated for by an increase in velocity. The right side of the figure shows the piloting accuracy for various conditions. The basic condition, using a rate-of-climb instrument of 25-feet-per second indication for final guidance into orbit, gave a piloting accuracy of $\pm 0.1^{\circ}$. Using sensitive or insensitive inertial altimeters increased the errors as shown. Reducing the damping augmentation to zero caused the vehicle to become difficult to control with sufficient accuracy to approach the desired orbital conditions consistently. It appears that the damping system must be extremely reliable. Although not shown, loss of the static stabilization system, resulting in an extreme value of aerodynamic instability during the first 200,000 feet of the trajectory, had little effect on the pilot's ability to establish a satisfactory orbit.

The effects of a malfunctioning climb program on the pilot's ability to place the vehicle at the desired orbital conditions were also investigated. The malfunctions simulated ranged from inaccurate and erratic indications to complete failure as early as 20 seconds after lift-off. The effect of these malfunctions was generally to increase the error in the final orbital altitude from the normal, ±2,000 feet, to about ±8,000 feet, which is still thought to be reasonable. The maximum deviation from the programmed altitude during the boost period was 20,000 feet, which might be critical for some vehicles. In all probability a complete presentation failure would cause the pilot to abort the flight; however, there are certain regions of the launch, as discussed in the previous section, in which it would be safer to attempt to establish the orbit. It appears the pilot can do this with satisfactory accuracy by using several altitude and speed check points during the climb.

Although the simulation used in this investigation was by no means optimum or even desirable, the results indicate that pilot guidance of a launching vehicle with adequate accuracy was feasible. It appears that proper design of presentation and proper use of the pilot may considerably reduce the complexity of the vehicle and increase its overall reliability, particularly in case of malfunctions.

Orbit Selection, Entry, and Landing

Although the orbital factors of eccentricity, altitude, and inclination each have a bearing on manned satellite operations, eccentricity is of very minor importance, provided it is reasonably small. The altitude of the orbit is of somewhat greater importance and will be determined primarily by the desired lifetime, ranging from near 100 miles for short-duration vehicles to altitudes above 300 miles for semipermanent installations.

The inclination of the orbit may determine, or be determined by, the factors of use, survival, and operational ease. With regard to use, military satellites will require, and geophysical satellites will probably desire, orbits as steep as 90°. Satellites for vehicular research have less stringent requirements, while permanent, high-altitude, space terminals will undoubtedly have equatorial orbits, inasmuch as this orbit has the greatest stability and passes over the same points on the earth on each rotation. Thus the observation, supply, and rendezvous problems are considerably simplified.

The vehicle survival potential of an orbit is primarily associated with the problems of entry, landing, and rescue following landing and therefore differs for the various configurations. Considering first the ballistic vehicle, malfunction during the launching operation could possibly cause the vehicle to land anywhere around the world, approximately on the first orbital path. In actuality, malfunctions over 90 percent of the boost period would cause impact in the first 6,000 miles and proper use of the retro rockets could, in any case, limit this distance to about 12,000 miles. Intentional landings on later orbits can occur, in general, anywhere between the extreme latitudes obtained by the orbit. The only azimuth control, in this case, is the crude one of choice of orbit on which to enter. To offset this lack of azimuth control, and thus minimize the area to be searched for rescue, the equatorial orbit is an obvious choice, if the mission permits.

The passenger does, of course, have complete freedom of choice in range, since he is able to fire his recovery rockets at any point in his orbit and thus land wherever he desires. The prediction of the impact point is least sensitive to errors if the retro rockets are fired at the apogee of an elliptical orbit, in which case the landing is made near perigee. The determination of the apogee point by the passenger will be relatively easy by use of a radio altimeter and clock. If everything progresses satisfactorily, a rather unlikely event, the point of landing can be predicted before launch within a circle perhaps 60 miles in diameter. In the more probable case in which the flight and recovery are not executed with the desired precision, the area to be searched may be considerably greater. Consideration of the launch malfunction problem mentioned before indicates a possible landing area of 12,000 miles by, perhaps, 100 miles. The difficulties of search and rescue in an area this large composed of open sea or jungle cannot be overemphasized. This problem may give the purely ballistic vehicle an inherently lower survival potential than the other two types.

The winged vehicle places fewer requirements on the inclination of the orbit because the pilot is able to modify the entry path both in range and azimuth and thus may navigate to land at preselected areas which may be considerably off the projected flight path. In a launch emergency this would require that only about six or seven emergency landing areas be available in the first 12,000 miles of the first orbital path. A similar condition exists for the intentional landing from satellite orbit. Figure 6 shows the lateral deviation available to the semiballistic or winged vehicles as a function of lift-drag ratio for entry from a 100-mile orbit. Even the lowest lift-drag ratios result in making a large area available for landing. Although only a portion of the area for the $L/D = 4$ condition is shown (area extends to $Y \approx 8,500$ miles at 20,000-mile range), this area is so large it is obvious that lift-drag ratios above 4 are probably not necessary for those satellite entry vehicles which can perform the complete entry at high lift-drag ratios. Figure 6 also shows a curve for the winged vehicle of a design such that aerodynamic heating requires the initial entry be made at a lift-drag ratio of unity down to a velocity of 16,000 feet per second, and a lift-drag ratio of 4 be available for the remaining distance. An indication of what this lateral maneuverability means to the pilot is given in figure 7, which depicts this latter case superimposed on a map. The large elliptical region indicates an area which, if intersected by the projected orbital track, will permit a landing anywhere within the smaller enclosed area. The orbits on which a possible landing could be made for the orbital conditions indicated are listed in the figure. In this case a landing could be made on any of the first four orbits and then on the tenth to the eighteenth. This gives the pilot greatly increased flexibility of operation both in normal operations and in case of emergency. An interesting point indicated here is that only slightly greater maneuverability would be required to enable landing in the continental United States from an equatorial orbit.

Such maneuverability can also be attained by use of thrust in space. However, the lateral deviation shown in figure 7 would require a mass ratio greater than 4 at a specific impulse of 250.

Consideration of the actual landing maneuver indicates a high probability of a water landing for the ballistic vehicle and a possibility of a similar landing for the other types. The vehicles should be designed, therefore, with water landing capability. The landing can be made by conventional landing gear or parachute with the winged vehicle, or by parachute with the ballistic vehicle.

The effects of orbit inclination on operational ease are considered only briefly. It is thought that the maximum operational ease will probably be attained with a winged-type vehicle launched and recovered within the continental limits of the United States, which restricts the inclination to greater than 20°. The equatorial orbit has the operational problems of shipboard or island launch of extremely large vehicles, logistics, the establishment of a seaborne range, and, in the case of the ballistic vehicle, search and rescue in a large area roughly 22 percent jungle and 78 percent water.

Range Requirements

Undoubtedly, manned operations will require exact position and trajectory data, monitor and command data link, communications, long-range GCA, and homing (for the winged vehicle) in certain parts of the orbit. The coverage desired of these facilities is again affected by the type of vehicle, while the number of installations is determined by this desired coverage and by the limits of line-of-sight radio propagation. This effectively limits any one installation to a radius of about 850 miles for an orbit altitude of 100 miles, and less for lower altitudes. These distances can be increased by about 1,200 miles for UHF communications by employing a repeater station in an aircraft at high altitude.

The range requirements of the ballistic and winged vehicles differ considerably, with the ballistic vehicle substituting complexity of ground installations for vehicle complexity. The winged vehicle, of necessity, has greater complexity in guidance and control than the purely ballistic type. The minimum coverage probably required for a ballistic vehicle in an equatorial orbit is shown in figure 8. This vehicle requires complete coverage, as shown, for a distance of about half way around the world for rescue in case of launch malfunction. The darker region shown in the Pacific Ocean is the primary launch and data-taking region while the other areas are, as indicated, only for location and communication. An additional station at 180° from the launch site is desirable for orbit verification and for aiding in entry initiation. It should be emphasized that this is the minimum coverage; for nonequatorial orbits it should be considerably increased, particularly when the possibility of an unscheduled flight termination is considered.

At the other extreme the minimum coverage required for the winged vehicle in a nonequatorial orbit is shown in figure 9. This coverage consists of the first 3,000 miles following take-off, the intermediate stations shown, and the last 2,000 miles before landing. The first region is used to monitor the take-off and initial portion of the orbit to make an initial determination of the orbit and check the pilot's instrument indications. The intermediate points are selected for orbit verification, to insure communication with the pilot at least once per revolution, and to assist the pilot in initiation of entry. The final coverage in the Pacific Ocean is in the nature of long-range GCA for the final approach. The intermediate points may well be chosen to provide coverage for the selected emergency landing areas.

It would probably be desirable during the launch operation and the first orbits to have the maximum communications coverage possible. The stations shown for the ballistic vehicle, of course, provide complete coverage for the first 12,000 miles, leaving about a 40-minute gap; whereas, those for the winged configuration leave gaps of as much as 20 minutes in which communications are lacking. As mentioned previously, this coverage can be improved easily and quickly on a temporary basis by use of airborne repeaters. The pilots have a natural desire for continuous worldwide communications; however, it appears improbable that such coverage can be achieved with a reasonable number of earthbound stations, particularly for nonequatorial orbits. A promising solution in this case is the provision of communication satellites in the "stationary" (22,000-mile altitude) orbit. The ability to establish such facilities may well precede the capability of establishing any but exploratory manned satellites.

Flight Testing

The flight test program should be included in any discussion of manned satellite operations. Any flight test program should utilize the usual procedure of a rational buildup of performance on successive flights in order to explore, with reasonable safety, successively higher performance ranges. This procedure would have the desirable effect of providing the longest period possible for the improvement and demonstration of booster reliability. The provision of boosters of sufficient reliability is, of course, one of the greatest obstacles to the accomplishment of manned orbital flight.

CONCLUDING REMARKS

Although this cursory survey has not indicated any insurmountable operational problems to manned orbital flight regardless of configuration type, it is indicated that the problems of the various satellite configurations do materially affect operations and must be considered early in the design. Safety and survival requirements must be taken into consideration in manned operations and may force appreciable deviation from optimum procedures. Although the presence of the human in the vehicle requires increased emphasis on reliability and safety, proper use of his abilities can greatly simplify design and increase reliability. The type of vehicle has a considerable effect on range requirements, the more simple vehicles requiring increased ground complexity for other than very special conditions.

High-Speed Flight Station,
National Advisory Committee for Aeronautics,
Edwards, Calif., April 12, 1958.

TABLE I

LAUNCH ESCAPE REGIONS

	APPROXIMATE CONDITIONS			PROBLEM	ESCAPE PROVISIONS
	H, MI	V, FT/SEC	q, LB/SQ FT		
A	0 TO 4	0 TO 1,000	0 TO 600	ESCAPE FROM LAUNCH AREA	1. BOOSTED FINAL STAGE 2. EJECTION SEAT
B	4 TO 20	1,000 TO 5,000	300 TO ≈1,500	AS FOR NORMAL OPERATION	1. FINAL STAGE
C	20 TO 90	5,000 TO 24,000	300 TO ≈ 0	POSSIBILITY OF EXCESSIVE g OR HEATING ON ENTRY	1. PROPER TRAJECTORY 2. FINAL STAGE (POWER ON, IF POSSIBLE)
D	>90	24,000 TO ORB.		AS FOR ENTRY FROM ORBIT	1. FINAL STAGE

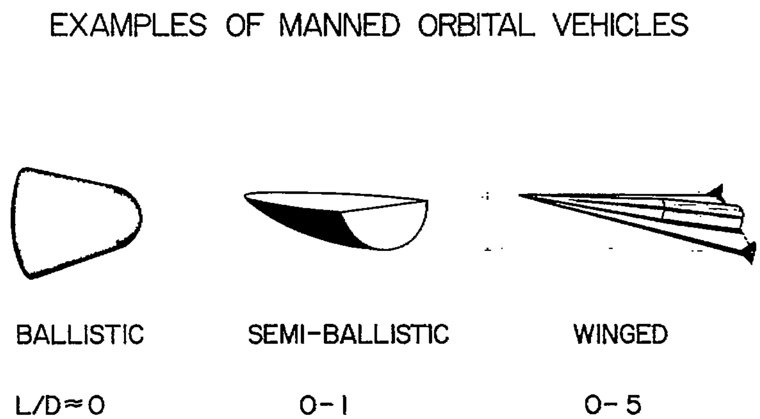

Figure 1

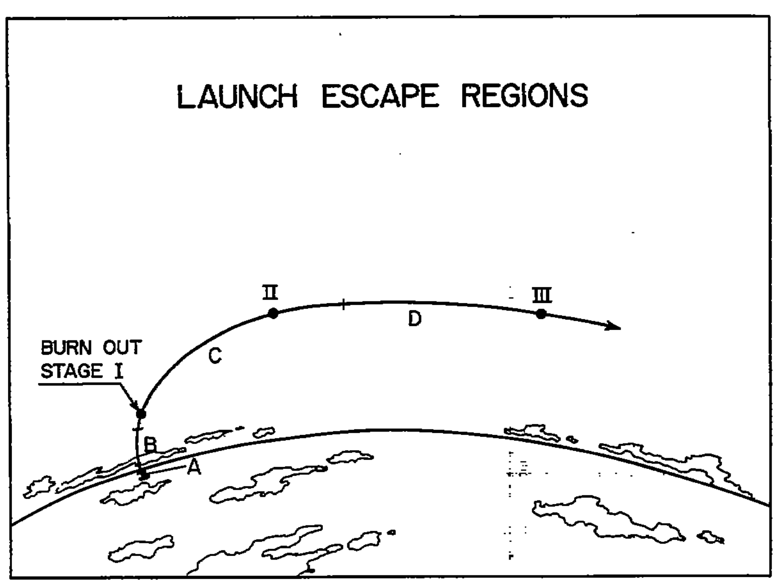

Figure 2

DECELERATIONS FROM ABORTED LAUNCH

BALLISTIC VEHICLE, 150 MILE ORBIT

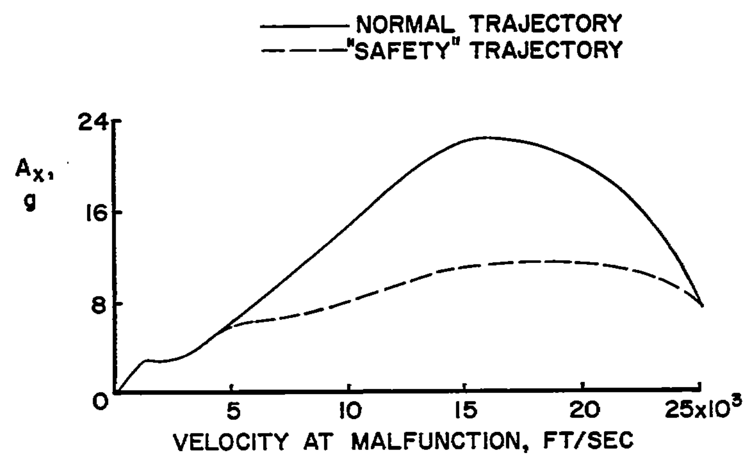

Figure 3

BALLISTIC VEHICLE LAUNCH TRAJECTORIES

ORBIT ALTITUDE, 150 MILES

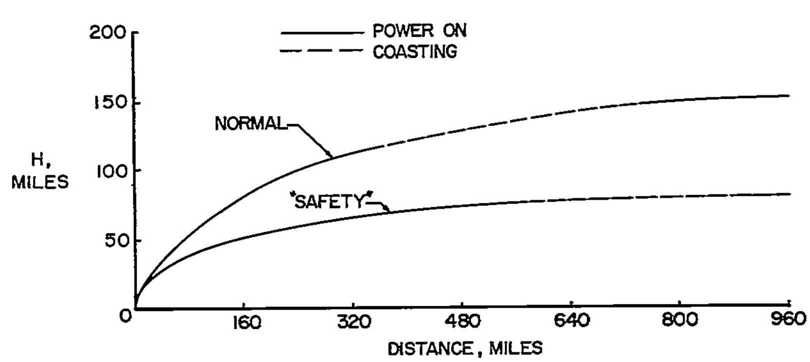

Figure 4

PILOTING ANGULAR ACCURACY AT BURNOUT

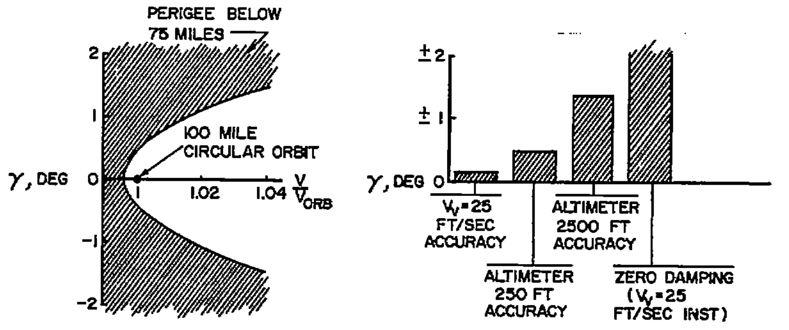

Figure 5

MANEUVERABILITY DURING ENTRY

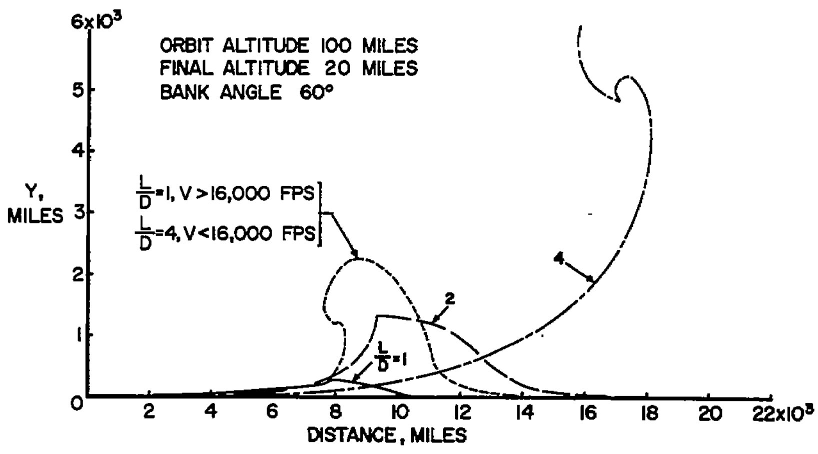

Figure 6

LANDING ORBITS

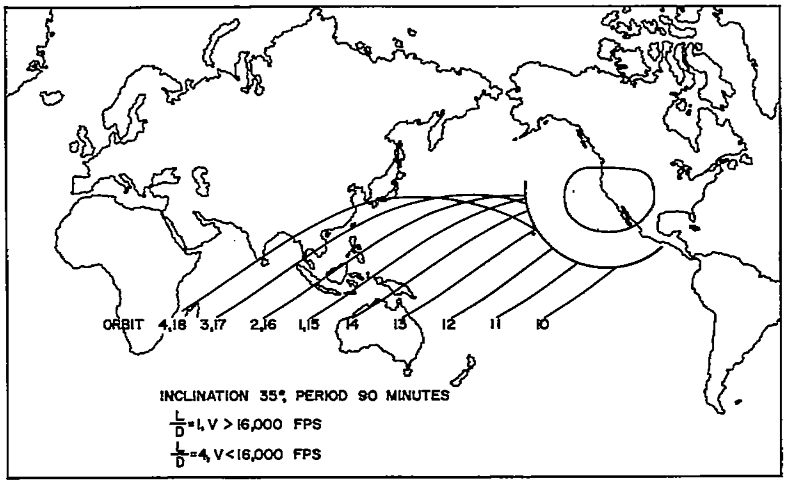

Figure 7

RANGE REQUIREMENTS
BALLISTIC VEHICLE

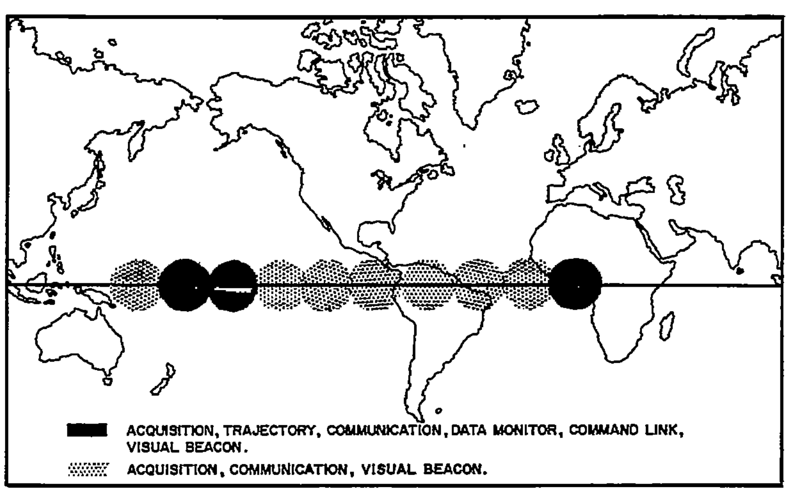

Figure 8

RANGE REQUIREMENTS
WINGED VEHICLE

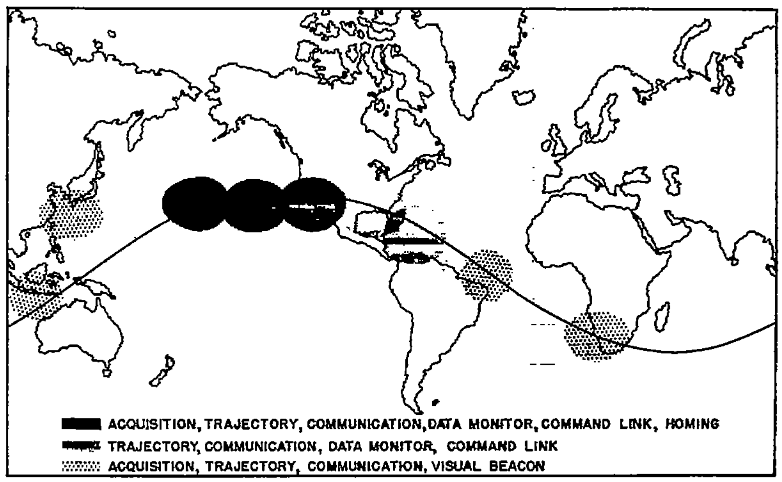

Figure 9

NACA - Langley Field, Va.